

# BIOSTRATIGRAPHICAL IMPLICATIONS OF A *CHUARIA-TAWUIA* ASSEMBLAGE AND ASSOCIATED ACRITARCHS FROM THE NEOPROTEROZOIC OF YAKUTIA

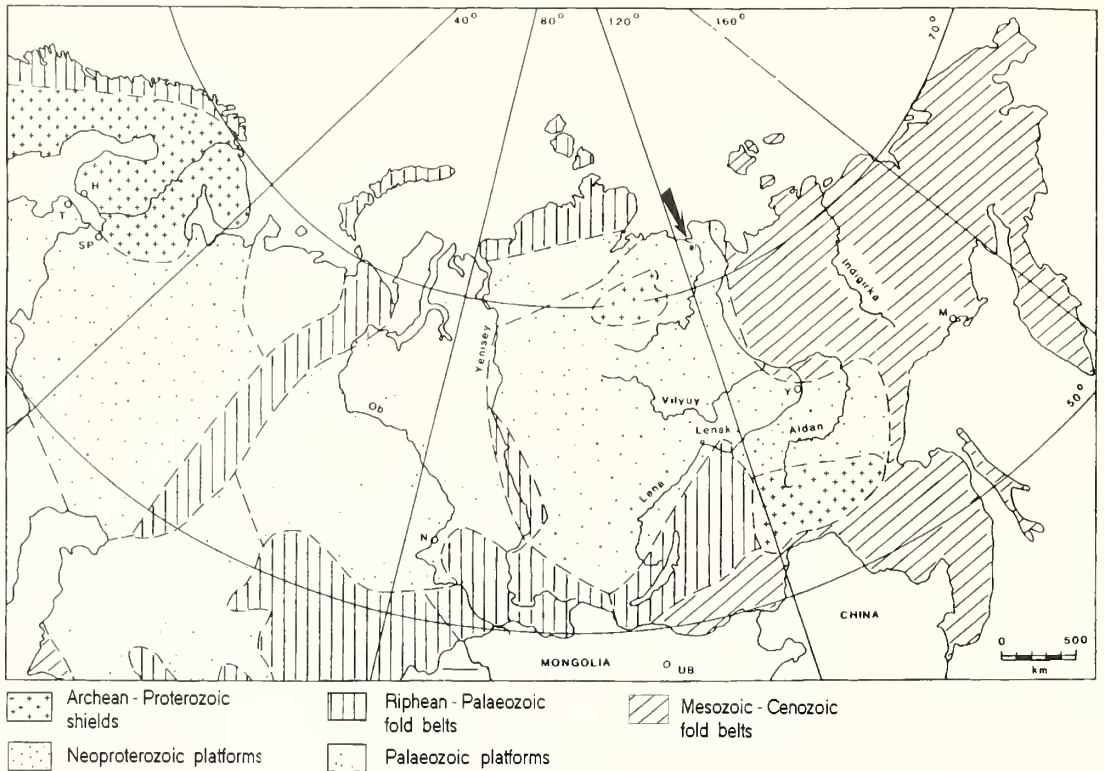
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**ABSTRACT.** A new occurrence of the carbonaceous fossils *Chuarina circularis* and *Tawuia dalensis* is reported from subsurface Neoproterozoic in the Khastakh 930 Borehole in the Lena-Anabar Depression, northern Yakutia. Neoproterozoic deposits in this region are regarded as belonging largely to the Yudomian Stage. There have been no faunal records from this site and the strata directly underlying fossiliferous Permian deposits are, on lithostratigraphical grounds alone, regarded as Cambrian. Preliminary palynological results here can be compared with other Neoproterozoic (late Riphean) occurrences of large and morphologically complex acanthomorph acritarch taxa such as *Trachyhystriosphera vidalii*. This biostratigraphically diagnostic taxon is associated with vase-shaped fossil protists and other diagnostic acritarchs also known from Upper Riphean strata elsewhere, placing this *Chuarina circularis-Tawuia dalensis* assemblage within the time interval of around 840–700 Ma. By comparison with other regions, the recovered fossils appear to indicate that the investigated succession is of Neoproterozoic (Late Riphean) age, thus preceding the Varanger glacial event.

PROTEROZOIC organic-walled microfossils have been reported from various regions of Siberia (Timofeev 1959, 1966, 1969; Rudavskaya 1971, 1973, 1980; Rudavskaya and Frolov 1974; Ogurtsova 1975; Timofeev *et al.* 1976; Volkova *et al.* 1980; Volkova 1981; Faizulina *et al.* 1982; Rudavskaya and Vasileva 1984; Sokolov and Fedonkin 1985; Sokolov and Ivanovsky 1985; Pjatiletov 1986). The vast majority of these finds are acritarchs (organic-walled envelopes of predominantly encysted life stages of taxonomically problematic single-celled algae: Downie 1973). In this paper, we report on a biostratigraphically significant occurrence of macroscopic, possibly algal, fossils identified as *Chuarina circularis* (Walcott) Vidal and Ford, 1985 and *Tawuia dalensis* Hofmann, 1979, from Proterozoic subsurface units in Yakutia, eastern Siberia.

## GEOLOGICAL BACKGROUND

Proterozoic rocks dealt with in this report are known to occupy a vast area in the Olenek region of northern Yakutia (Text-fig. 1; Sokolov and Fedonkin 1985). Neoproterozoic (Vendian) deposits in the region belong to the Yudomian Stage (Sokolov and Fedonkin 1985) and are generally overlain by detrital rocks of the Kessyusa Formation (partly referred to the Cambrian). The Kessyusa Formation rests with erosional contact on the Turkut Formation (Text-fig. 2). At the investigated Khastakh drilling site, no faunal record is presently known from rock units underlying fossiliferous Permian deposits. On lithostratigraphical grounds alone, the immediately sub-Permian rocks were considered to contain the entire Cambrian System, whereas the lower 120 m of the 230 m thick Kessyusa Formation were regarded as Vendian in age. On a regional scale, the Yudomian is considered roughly time-equivalent to the Vendian. However, correlations were constructed on rather circular arguments, using 'phytolite' assemblages (Sokolov and Fedonkin 1985, p. 181).



TEXT-FIG. 1. Main structural units and location of the Khastakh 930 Borehole (arrow) in the Lena-Anabar Depression, Yakutia. H, Helsinki; T, Tallinn; SP, St Petersburg; N, Novosibirsk; Y, Yakutsk; M, Magadan; UB, Ulan Bator.

In the North Atlantic region, the East European Platform and elsewhere, the Varanger glacial deposits are used to define the Varanger glacial episode, which is generally considered to mark the base of the Vendian (Sokolov and Fedonkin 1985; Harland *et al.* 1990). Despite poor isotopic and palaeontological dating, they are generally regarded as being the result of virtually contemporaneous glacial events (Chumakov 1981; Chumakov and Semikhatov 1981). The recognition of the Lower Vendian is mainly a matter of recognizing these predominantly glacial deposits (Chumakov 1981). However, the absence of Neoproterozoic glacial deposits in the part of the Anabar Slope of Yakutia involved in this study presents major obstacles for the unequivocal recognition of the Lower Vendian (Sokolov and Fedonkin 1985).

In areas outside Siberia, the Upper Vendian is normally recognized by the presence of distinctive non-skeletal metazoans and/or vendozoans (Seilacher 1989), and belongs to the Ediacara Series (Glaessner 1982; Cloud and Glaessner 1982; Harland *et al.* 1990). However, the strength of this argument is weakened by recent finds of Ediacaran fossils in intertillite beds in northwestern Canada (Hofmann *et al.* 1990). Interestingly, components of the Ediacaran fauna were reported from outcrops of the Khatyspyt Formation along the River Khorbusuonka and River Olenek, thus roughly suggesting time equivalence with Redkino 'Horizon' rocks of the Upper Vendian Valdai 'Series' in the East European Platform (Sokolov and Fedonkin 1985, p. 134). No such faunal components were ever observed in the rock succession dealt with in this report.

The sub-Permian sequence penetrated by the Khastakh 930 Borehole (Text-Fig. 2) is dominated by carbonate rocks largely consisting of dolostones with (as far as visible in examined cored intervals) a general lack of primary sedimentary structures. On the whole, the carbonates are

TEXT-FIG. 2. The investigated Neoproterozoic sequence in the Khastakh 930 Borehole, Lena-Anabar Depression, Yakutia. After Grausman, Vinokurov and Savinko, unpublished logging data, 1989, Geological Production Corporation, Lena Gas and Oil Geology, Yakutsk.



beige, buff and red, and thus have very low content of organic carbon. But there are remarkable exceptions in the form of bituminous, thinly laminated limestones at depths of 3108·0–3111·9 m, 2576·9–2572·4 m, 2482·1–2487·6 m and 2425·0–2433·0 m.

The presence of red beds consisting of feldspathic sandstones and red and crimson mudstones was noted at various levels in the sequence (Text-fig. 2). Conglomerates, arkoses (often cross-bedded) and tuffaceous beds occur at various levels. Haematite-rich, laminated mudstones occur in close stratigraphical proximity at 2903·9–2910·0 m and 2910·0–2916·7 m. This, and the occurrence of gypsum casts, at least at two levels, suggests sedimentation in a periodically nearly closed depositional setting. There were periods of sediment starvation, that resulted in the accumulation throughout the sequence of organic-rich, phosphoritic and strongly fossiliferous levels. This succession is similar to other known Neoproterozoic (Riphean and Vendian) sequences in intracratonic settings, that accumulated as a comparable set of facies associations.

#### MATERIAL AND METHODS

Only small intervals of the Khastakh 930 Borehole were cored. The succession shown in Text-figure 2 was compiled from unpublished logging information provided by the Geological Production Corporation, Lena Gas and Oil Geology, Yakutsk (V. V. Grausman, B. N. Vinokurov and N. A. Savinko, pers. comm.). Cored intervals were examined and in some instances samples were collected. The detailed examination of bedding surfaces revealed numerous organic films and preliminary results from study in progress of HF-resistant organic residues indicate the presence of very abundant acritarchs.

Specimens of *Chuarina circularis* and *Tawuia dalensis* were found at eight levels within the borehole, in dark-grey and black, often phosphatic mudstones and shales (Text-fig. 2). At one of these levels, in the upper Khajpakh Formation, abundant acritarchs were also recovered.

Generally, bedding surfaces in fossiliferous shales from the Debengdin, Khajpakh, Maastakh and Khatyspyt Formations, display an extraordinary abundance of irregularly shaped organic films. Only a minority of the organic remains can be definitely identified as fossils. However, most of the filmy fragments are probably fragmented fossils, as suggested by the fact that rather large fragments of *Chuarina* and *Tawuia* were also observed.

Specimens with the prefix PMU-Sib are in the collections of the Institute of Palaeontology, Uppsala University, Uppsala; those with the prefix VNIGRI followed by a number are deposited at the All-Union Scientific Research Geological Prospecting Institute in St Petersburg. In relevant cases, the location of specimens in microscopic slides is given by England Finder coordinates (specimens in Plate 1, figs 1–4; Text-figures 5A–B, 6A–C). Micrographs of figured specimens of *Chuarina* and *Tawuia* were taken using a Wild Photomakroskop M 400 and incident light sources. Acritarchs were concentrated in permanent mounts using standard palynological techniques and micrographs were taken under an interference contrast microscope.

#### SYSTEMATIC PALAEOLOGY

Group ACRITARCHA Evitt, 1963

Genus CHUARIA (Walcott) Vidal and Ford, 1985

*Type species.* *Chuarina circularis* (Walcott) Vidal and Ford, 1985, from the Neoproterozoic Chuar Group in northern Arizona, U.S.A.

*Chuarina circularis* (Walcott) Vidal and Ford, 1985

Text-figs 3A–D; 4B, D

1894 Unnamed, Wiman p. 109, pl. 5, figs 1–5.



- 1899 *Chuarua circularis* Walcott p. 234, pl. 27, figs 12–13.  
 1966 *Chuarua wimani* Brotzen; Eisenack, p. 52, figs 1–2.  
 1969 *Trachysphaeridium vetterni*, Timofeev, p. 21, pl. 4, fig. 3.  
 1970 *Kildinella magna* Timofeev; Timofeev, p. 158, pl. 1, fig. D.  
 1973 *Chuarua circularis* Walcott; Ford and Breed, p. 539, pl. 61, figs 1–7, pl. 62, figs 1–6, pl. 63, figs 1–4.  
 1974 *Chuarua circularis* Walcott; Vidal, p. 6, pl. 1, figs 3–6.  
 1976 *Chuarua circularis* Walcott; Vidal, p. 18, fig. 8A–H.  
 1979 *Chuarua circularis* Walcott; Vidal, p. 19, pl. 4, figs a–b.  
 1981 *Chuarua circularis* Walcott; Vidal, p. 23, fig. 11J–K.  
 1985 *Chuarua circularis* Walcott; emend. Vidal and Ford, p. 355, fig. 3A.  
 1987 *Chuarua circularis* Walcott; Sun, p. 115, pl. 1, figs 1–8, pl. 4, figs 1–2.  
 1990a *Chuarua circularis* (Walcott) Vidal and Ford; Vidal, p. 488, fig. 1.  
 1992 *Chuarua circularis* (Walcott) Vidal and Ford; Amard, p. 121, pl. 1, figs 1–8; pl. 2, figs 1–8.

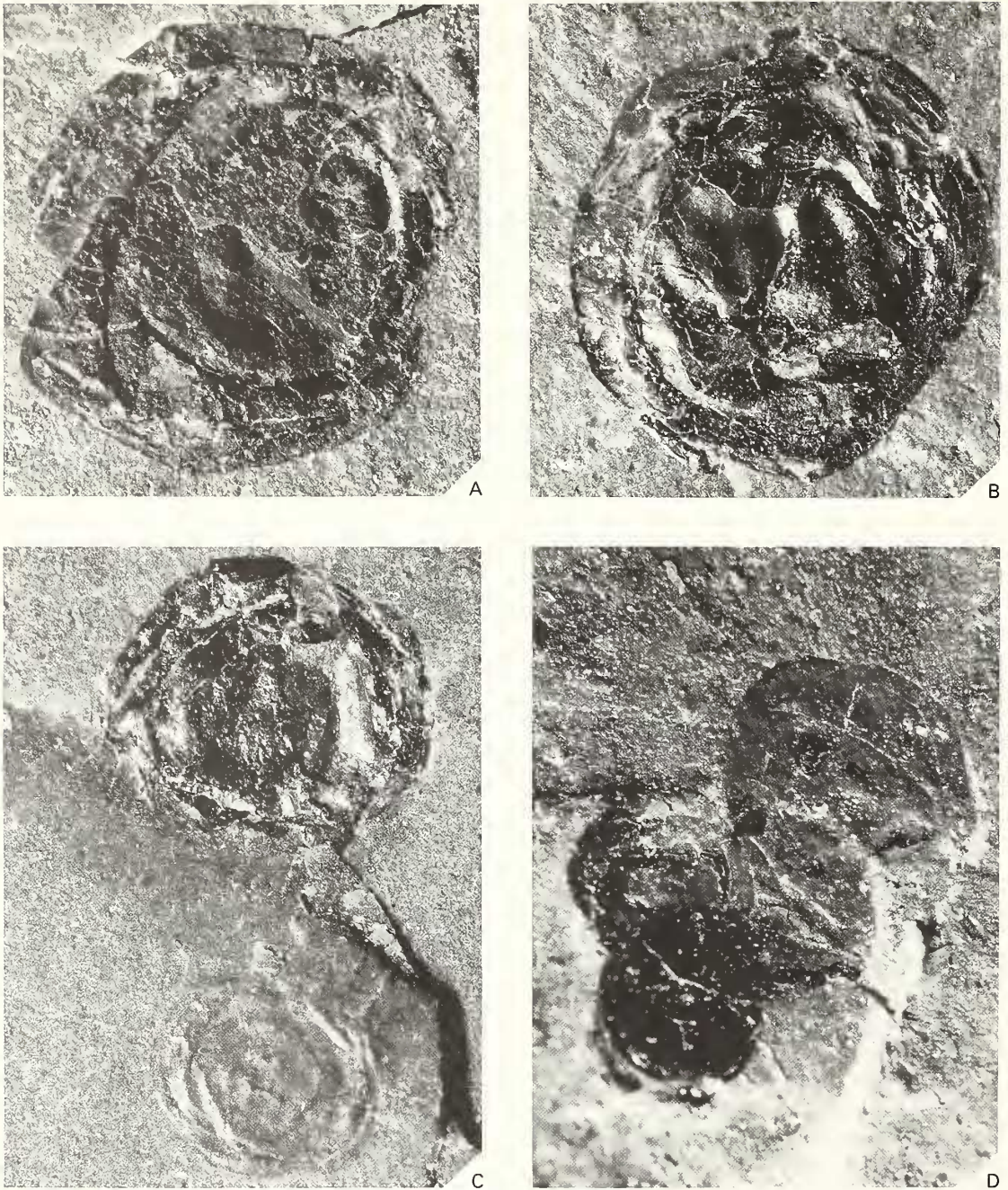
*Description.* Specimens consist of compressed discoidal structures (Text-fig. 3A–C) preserved as slightly convex carbonaceous vesicles, ranging from 500 to 3000  $\mu\text{m}$  across and displaying sets of irregular and sharp compression folds. The specimens are identical to discoid fossils attributed to *C. circularis* from, for example, the Neoproterozoic (late Riphean, > 700 Ma; Text-fig. 7) Visingsö Group in Sweden. As with occurrences elsewhere (e.g. Vidal 1976; Vidal and Siedlecka 1983; Vidal and Ford 1985; but see Sun 1987 for a different standpoint) the present material can be liberated by careful HF maceration.

*Remarks.* Undoubtedly, the very simple morphology of the near-macroscopic, flattened, spheroidal alga presents significant problems for a sound taxonomic treatment (see for example discussions in Vidal and Ford 1985 and Sun 1987). From this lack of clearly diagnostic characters emanates the suspicion that *C. circularis* may in fact be a taxonomic waste-basket containing true biogenic, as well as various non-biogenic objects such as films of organic sapropel and carbonaceous intraclasts (Horodyski 1980). The true biotic category may include accumulations of bacterial (Moczydlowska and Vidal 1988, p. 6) or cyanobacterial filaments (Horodyski 1980), the latter perhaps including objects explained as possible *Nostoc* balls by Sun (1987, p. 118). However, the variably degraded, discoid fossils attributed to *C. circularis* (Vidal 1974, 1976) have thick sturdy ‘sporopollenin-like’ (Eisenack 1966) organic walls, very different from the thin outer layer of true *Nostoc* balls (whose likelihood of surviving into the fossil record must be regarded as extremely low). Nevertheless, mechanical and chemical degradation introduce into the fossil record features (Vidal 1974; 1976, fig. 8E–H) that are prone to inflate the flora with superfluous taxonomic combinations. The same degradationally introduced features are observable in nearly macroscopic (c. 600  $\mu\text{m}$  in diameter) specimens of *Tasmanites* (G. Vidal, unpublished data). Contrary to suggestions by Sun (1987), specimens of *C. circularis* from the Neoproterozoic Visingsö Group displaying degradational features resulting from intensive pyrite growth and sapropelization, have no traces of trichomes. In addition, specimens from the Upper Proterozoic Chuar Group (Vidal and Ford 1985) display a visible level of chemical degradation (Vidal 1990a) higher than that of some of the rather ‘fresh’ material from the Visingsö Group in Sweden.

In conclusion, the problematic status of these fossils is due to the variety of possibly unrelated objects included under the common umbrella of the name *C. circularis*. In this connection, it is worth mentioning that fossils tentatively attributed to *Chuarua* from the Upper Proterozoic (Vendian) Pusa Formation in central Spain (Palacios 1989) may, as suggested by Sun (1987), have little to do with both the Upper Riphean and the clearly pre-Varangerian occurrences of *Chuarua*. This Spanish material consists of thin-walled specimens that are one degree of magnitude larger than any specimens of *Chuarua* recorded from older units. The age of the Spanish material is quite certainly late Vendian (Palacios 1989; Palacios and Vidal 1992) as clearly indicated by the association with vendotaenids, ichnofossils, the early skeletal fossil *Cloudina* (Grant 1990) and the immediately overlying Lower Cambrian strata.

As it stands, it seems that various clearly biogenic objects are involved in the concept of *C. circularis* as currently in use. This concept prevents proper evaluation of its biostratigraphical





TEXT-FIG. 3. *Chuaria circularis*. Khastakh 930 Borehole; Upper Riphean; specimens showing various stages of preservation (A, D from the Debengdin Formation; B–C from the Khajpakh Formation). A, PMU-Sib.7; specimen slightly convex with concentric compaction folds and partly preserved carbonaceous wall; depth 3280.2–3286.6 m. B, PMU-Sib.8; convex specimen with organic wall only partly preserved (left side); at the bare areas the imprint is observable on the rock surface; depth 3108.2–3111.9 m. C, PMU-Sib.9; two specimens preserved as flattened carbonaceous vesicles (upper) and as the vesicle imprint (lower) on the rock surface; depth 3108.2–3111.9 m. D, PMU-Sib.10; group of four specimens preserved with organic wall (lower portion) and as imprints (upper portion); depth 3158.0–3165.0 m. All specimens  $\times 30$ .

usefulness. A more useful approach for establishing the taxonomic status of *Chuarina* may be through ultrastructural studies (e.g. Amard 1992). Nevertheless, despite a generalized morphology, it is clear that the sub-Varangeran smaller discoid fossils, ranging into the microscopic realm (Vidal and Ford 1985) or only considered at the sub- or macroscopic level (Sun 1987), appear restricted to a broad interval of strata pre-dating the Varanger glacial deposits (marking the base of the Vendian; Harland *et al.* 1990). These deposits also yield other probable algal fossils (such as *Tawuia* Hofmann and Aitken, 1979; Hofmann 1985; Sun 1987) and a distinctive assemblage of ornamented spheromorph and acanthomorph acritarchs (Vidal and Knoll 1983, Jankauskas *et al.*, 1989).

## INCERTAE SEDIS

Genus *TAWUIA* hofmann, 1979

*Type species.* *Tawuia dalensis* Hofmann, 1979; from the Neoproterozoic Little Dal Group, Mackenzie Mountains, Canada.

*Tawuia dalensis* Hofmann, 1979

Text-fig. 4A, C

- 1979 *Tawuia dalensis* Hofmann in Hofmann and Aitken, p. 158, fig. 13A-1.  
 1985 *Tawuia dalensis* Hofmann; Hofmann, p. 334, pl. 35, figs 1-3, 6; pl. 36, figs 1-5, 7-11.  
 1982 *Tawuia dalensis* Hofmann; Knoll, p. 3, figs 12-14.  
 1987 *Tawuia dalensis* Hofmann; Sun, p. 123.

*Description.* Fossils attributed to this species include one almost complete specimen 1 mm wide and 5 mm long with rounded ends, from the Debengdin Formation (Text-fig. 4C), and three fragmentary specimens from the Khajpakh and Khatyspyt Formation (Text-fig. 4A). They consist of flattened, organic, carbonaceous ribbons. One specimen (Text-fig. 4A) displays clear compaction wrinkles. The specimens are in the lower size-range indicated by Hofmann and Aitken (1979) and Hofmann (1985) for material from the Little Dal Group.

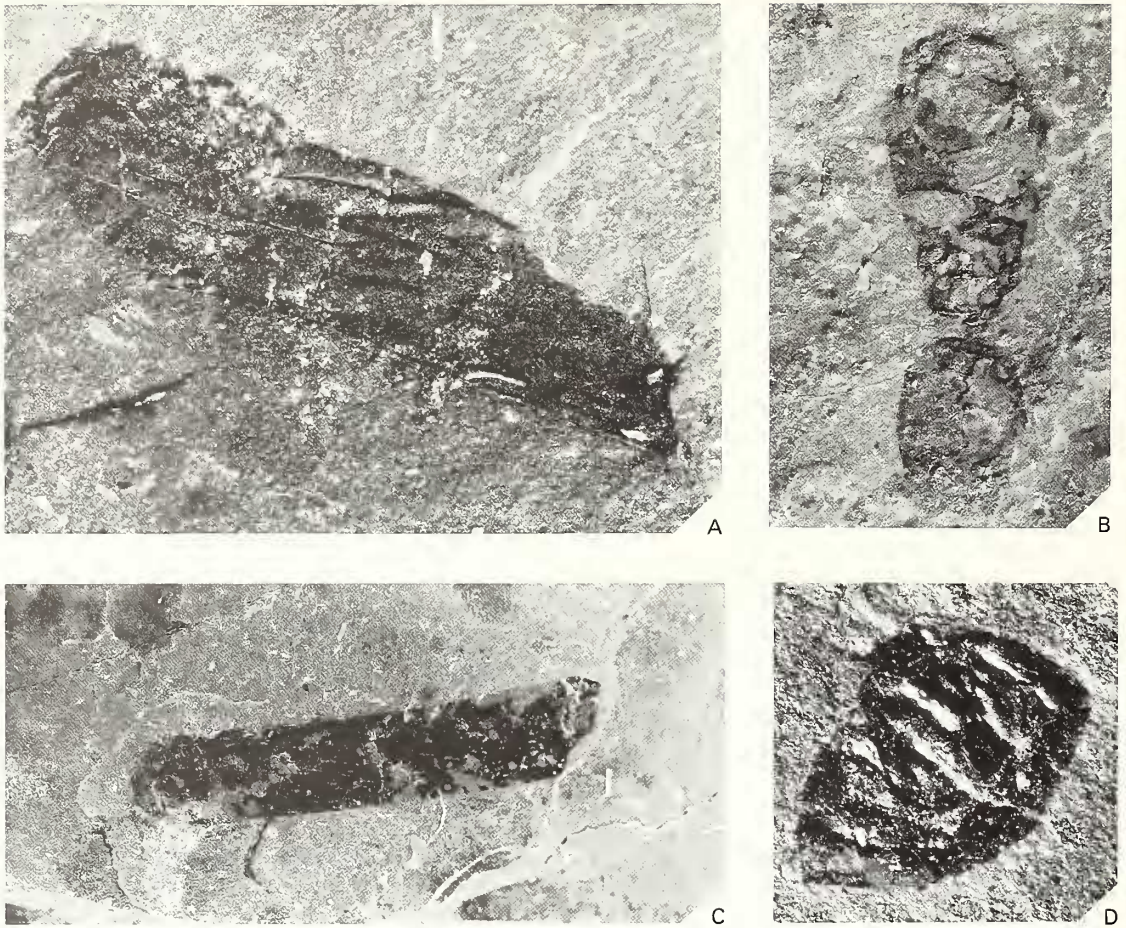
*Remarks.* The present material adds little to the problematic biological affinity of *Tawuia*. Sun (1987) put *Morania? antiqua* Fenton and Fenton, 1937 (*sensu* Hofmann and Aitken 1979) in synonymy with *T. dalensis*. Organic films comparable to *M.? antiqua* occur in the present material, and we consider *M.? antiqua* as probably part of *T. dalensis*; not having examined the original material of *M.? antiqua* we refrain from placing the latter in synonymy.

The two most extensively investigated collections of *T. dalensis* derive from the Little Dal Group (Hofmann 1985; 146 specimens) and the Kapp Lord Formation in Nordaustlandet, Svalbard (125 specimens attributed to *T. dalensis*; Knoll 1982). From the point of view of morphological variability these collections constitute formidable assemblages. To these should be added more than 20 specimens from North China (Sun 1987, p. 113, who pointed out that the bivariate plot for specimens of *T. dalensis* from the Kapp Lord Formation may include specimens of *C. circularis*; this assumption may be correct for at least the smallest specimens reported by Knoll, 1982, p. 275).

The biological nature of *T. dalensis* could perhaps be inferred from an analysis of their possible habitat, as deduced from a study of the encompassing sediments. Nevertheless, little is known about the depositional setting and environmental constraints of the material from the North China Platform. Apart from general statements indicating the shallow marine nature of the strata, this is also true of the whole Franklinsundet Group in Nordaustlandet (e.g. Flood *et al.* 1969). The occurrence in the Kapp Lord Formation was considered to have been preserved in a coastal mud-flat (Knoll 1982, p. 275), whereas the original occurrence from the Little Dal Group is in deep-water carbonate-clastic rhythmite (Hofmann and Aitken 1979, p. 153).

Environmental constraints on the present occurrences of *T. dalensis* are imposed by facies associations and sedimentary structures (see above). Dominated by carbonates (Text-fig. 2), the Khastakh succession includes deposits that probably formed in braided-plain and coastal





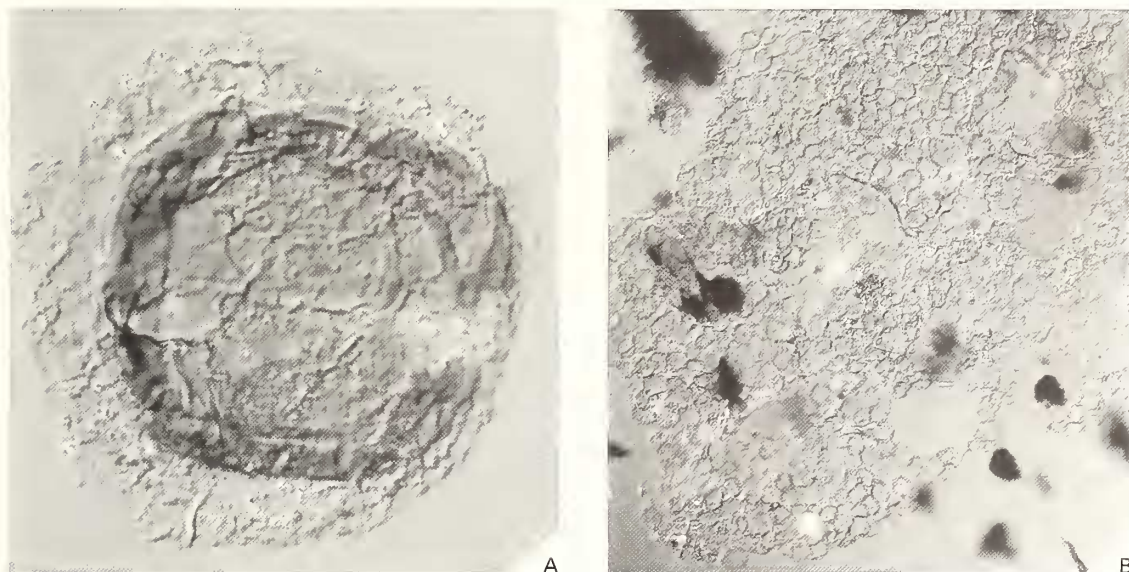
TEXT-FIG. 4. A, C, *Tawuia dalensis*; Khastakh 930 Borehole; Upper Riphean (A from the Khajpak Formation, C from the Debengdin Formation); A, PMU-Sib.15; specimen deformed by lateral compaction resulting in elongated folds and fracturing, end partly broken; depth 3108.2–3111.9 m,  $\times 30$ ; C, PMU-Sib.17; specimen with rounded end (left) and partly broken right end; depth 3280.2–3286.6 m,  $\times 12$ . B, D, *Chuarua circularis*; Borehole Khastakh 930; Upper Riphean (from the Debengdin Formation). B, PMU-Sib.16; imprints of two specimens; depth 3403.5–3410.0 m,  $\times 10$ ; D, PMU-Sib.18; complete compressed organic vesicle; depth 3158.0–3165.0 m,  $\times 30$ .

environments that seem to pass gradually into cycles of carbonate and evaporite deposition. These features suggest deposition in a periodically restricted shallow basin, which is significantly different from the environment inferred for the Little Dal occurrence. At the least, the final burial sites of the *Chuarua*–*Tawuia* assemblages represent different depositional settings. The biological affinity of *Chuarua* and *Tawuia* cannot be certainly established on the basis of the available evidence. However, it seems reasonable to assume that *Tawuia* represents a thallophytic level of organization that possessed considerable environmental and geographical dispersal.



## BIOSTRATIGRAPHY

Samples collected at various cored intervals are the subject of an investigation in progress, to recover organic-walled microfossils. Some significant results can be already advanced at this stage, in particular that acritarchs, together with possible algal tissues or cell aggregates (Plate 1, figs 1–4; Text-figs 5A–B, 6A–C) are quite abundant.



TEXT-FIG. 5. A, *Simia annulare*; specimen PMU-Sib.6-M/40/1; Khastakh 930 Borehole; Upper Riphean (from the Khajpakh Formation); depth 2903.9–2910.0 m,  $\times 1320$ . B, fragment of possible algal tissue; specimen PMU-Sib.6-G/56/3; Khastakh 930 Borehole; Upper Riphean (from the Khajpakh Formation); depth 2903.9–2910.0 m,  $\times 240$ .

Stratigraphically significant acritarchs have thus far been recovered at the depth of 2903.9–2910.0 m. Among them are abundant specimens of *Simia annulare* (Timofeev) Mikhailova and Jankauskas (Text-fig. 5A), rare specimens of *C. circularis* (including fragments of macroscopic and smaller specimens), various *Leiosphaeridia*, unnamed cell aggregates possibly comparable to *Ostiana microcystis* Herman (Text-fig. 5B) and three specimens of *Trachyhystrichosphaera vidalii* Knoll (Plate 1, figs 1–4; Text-fig. 6A–C). The latter is in our view a synonym of *T. stricta* Hermann, 1989 (*in* Jankauskas *et al.* 1989, p. 47) from the Upper Riphean Miroedikha Formation in Siberia.

*T. vidalii* (Plate 1, figs 1–4; Text-fig. 6A–C) possesses tubular processes that communicate with the cavity of the vesicle. The processes appear to have open distal portions and are enclosed by a thin organic membrane that is substantially thinner than the central vesicle. *T. vidalii* was interpreted as possibly representing various growth stages of a prasinophycean green alga (Knoll *et al.* 1991). While this is plausible, it is also possible that, as discussed below for *C. circularis*, large Neoproterozoic acritarchs such as *T. vidalii* could represent reproductive stages of thallophytic algae (Vidal 1990b, p. 290).

## SIGNIFICANCE OF THE BIOTA

Most previous occurrences of *Chuarina*–*Tawuia* assemblages are not associated with identifiable acritarchs. They thus cannot be placed in the acritarch biostratigraphy, which is only occasionally linked to isotopic ages. To evaluate the relative age of the Khastakh assemblage consideration of

various previously investigated sequences in Baltica, Svalbard, North America and China is required (Text-fig. 7).

The geographically closest comparable assemblage is in the supposedly Upper Riphean Miroedikha Formation, in the River Miroedikha area of central Siberia, from which Timofeev (1969) reported a later synonym of *C. circularis* (*sensu* Vidal and Ford 1985). This unit also yielded *T. stricta* (= *T. vidalii*; see above). However, the age of the Miroedikha Formation is poorly constrained. A late Riphean age attributed to the *Chuar*–*Tawuia* assemblage from the Kapp Lord Formation in Nordaustlandet (Svalbard) is inferred from rare acritarchs (Knoll 1982, p. 275) and from comparisons with biotas from the late Riphean Eleonore Bay Group in East Greenland (Vidal 1979). A late Riphean age is attributed to the Little Dal Group also based on palaeontological evidence (Vidal and Ford 1985, p. 380). The discovery in Yakutia of *Chuar* and *Tawuia* with *T. vidalii* provides further support to the age of the assemblage.

A co-occurrence of *Chuar* with *S. amulare* and several taxa attributed to *Trachyhystrichosphaera* (most likely conspecific with *T. vidalii*) was reported from the Neoproterozoic Kildin Group in Kildin Island, Russia (Lyubtsov *et al.* 1989). The absolute age of the Kildin Group, poorly constrained by K/Ar isotopic dating of glauconite from the lower part of the group, is at Sredniy Peninsula 1059–762 Ma and at Kildin Island 1015–849 Ma (Lyubtsov *et al.* 1989). Additional dating according to Polkanov and Gerling (1961) is between 1655 and 920 Ma for rocks at Sredniy and 887–715 Ma for rocks in Ribachiy Peninsula.

An interesting co-occurrence of vase-shaped microfossils with *T. vidalii* was reported by Knoll and Calder (1983) from the Ryssö Formation at the top of the Murchisonfjorden Group in Svalbard. While no isotopic ages are available for these beds, their relatively lower stratigraphical position with respect to the Varangerian correlative glacial deposits of the Gothia Group (Knoll 1982) and their biostratigraphical correlation with strata of the pre-Varangerian Eleonore Bay Group, suggest a late Riphean age around a broad estimate of 800–700 Ma (Knoll and Calder 1983, p. 469). According to Knoll *et al.* (1991, p. 53) the age estimates are also supported by comparisons with other rock units that were investigated using stable and radiogenic isotopes. As an interesting parallel, *C. circularis* and vase-shaped microfossils co-occur in the isotopically dated Visingsö Group (*c.* 800–700 Ma according to Rb–Sr datings of whole-rock shale and clay minerals by Bonhome and Welin 1983). Isotopically dated groups of strata underlying the Varanger glacial deposits in northern Norway (Beckinsale *et al.* 1975) are particularly important for determining the age of acritarch assemblages that include *C. circularis* (Vidal and Siedlecka 1983).

Although not associated with *C. circularis*, a reported occurrence of *Trachyhystrichosphaera vidalii* and *T. magna* (most likely a junior synonym of the former), vase-shaped microfossils, e.g. *Hyalocyrillium clardy* Allison (Allison and Awramik 1989), spheromorphic acritarchs and cyanobacterial and possibly fungal microfossils in the upper Tindir Group, Northwest Canada, has an indirect bearing on the age bracketing of the *Chuar*–*Tawuia* assemblage. The Upper Tindir Group was originally considered as possibly latest Proterozoic or early Cambrian (Allison and Awramik 1989). Recent biostratigraphical and chemostratigraphical evidence is consistent with a late Riphean age for the Upper Tindir microfossil association (Kaufman *et al.* 1992).

In North China, *C. circularis* and *T. dalensis* occur in the Liulaobei and Jiuliqiao Formations of the Huainan and Feishui Groups, dated respectively as 840 Ma (Rb–Sr on whole-rock shale) and 740 Ma (K–Ar on glauconite; Sun 1987, p. 113). The stratigraphically most significant occurrences of *Chuar*–*Tawuia* and associated time-diagnostic microfossils are shown in Text-figure 7.

#### EXPLANATION OF PLATE I

Figs 1–4. *Trachyhystrichosphaera vidalii* Knoll. Specimen PMU-Sib.6-N/43/3; Khastakh 930 Borehole; Upper Riphean (Khajpak Formation); depth 2903.9–2910.0 m. 1, 3–4, detail portions of the vesicle showing tubular processes with free communication with the vesicle cavity and enclosed by transparent organic membrane,  $\times 960$ . 2, complete specimen,  $\times 380$ .





1



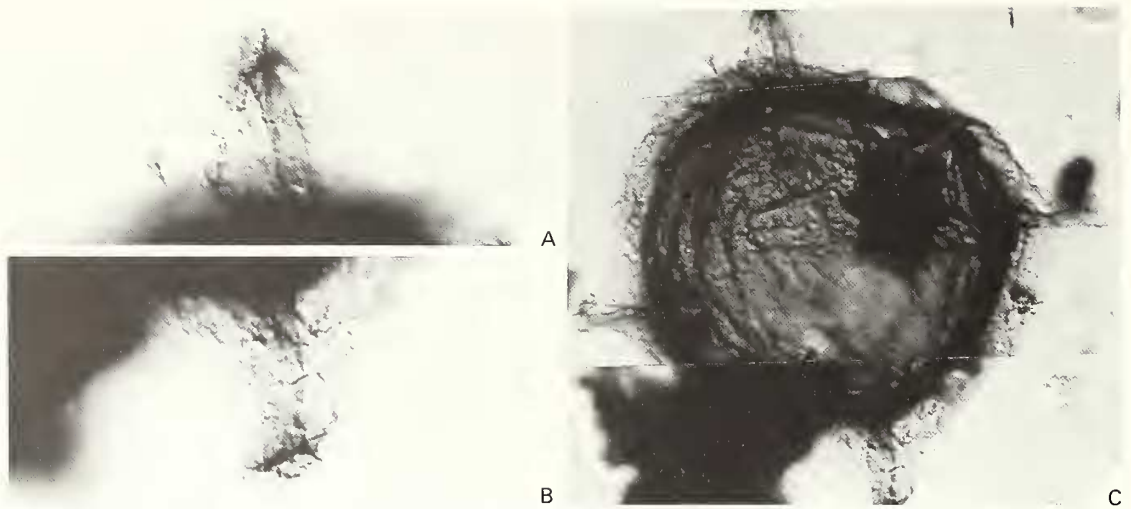
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3



4



TEXT-FIG. 6. *Trachyhystrichosphaera vidalii*. Specimen VNIGRI. 3559/2-u/63; Khastakh 930 Borehole; Upper Riphean (from the Khajpakh Formation); depth 2903.9–2910.0 m. A–B, detailed views of processes and membrane,  $\times 960$ . C, complete specimen,  $\times 550$ .

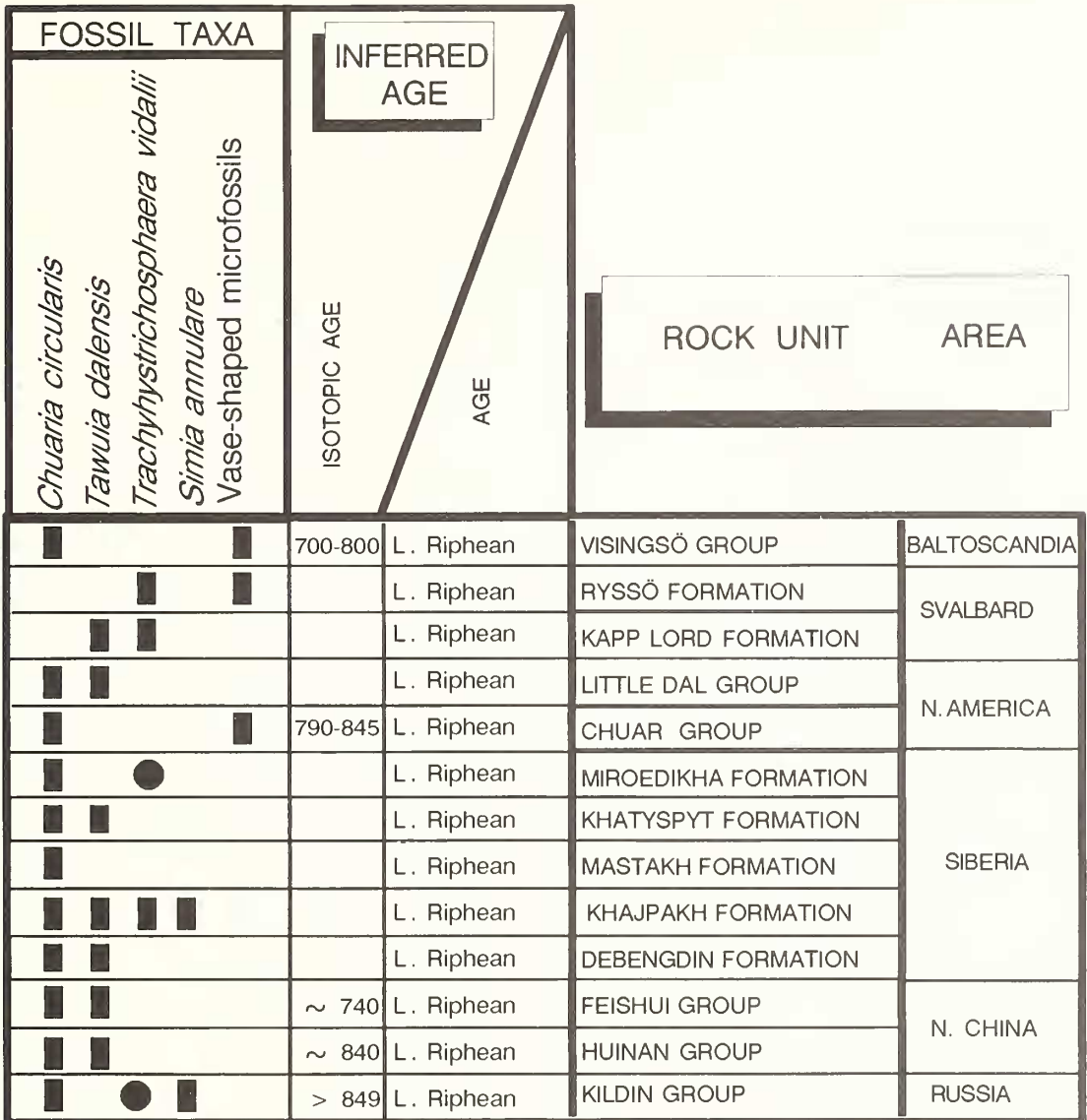
### CONCLUSIONS

Despite repeated study, the biological affinities of the acritarch *C. circularis* and the possibly algal fossil *Tawuia* remain uncertain. A number of hypotheses have been advanced concerning the nature of *C. circularis* and various other related palaeontological and possibly non-biogenic objects. The hypothesis favoured here is that *C. circularis* represents the compressed envelope of a planktic algal protist, possibly a prasinophycean green alga, often reaching macroscopic dimensions (Vidal and Ford 1985). However, the alternative hypothesis of *C. circularis* representing compressed *Nostoc* colonies (Sun 1987) is probably equally plausible. Whether *C. circularis* is in some way (more than by occurrence) related to *T. dalensis* remains uncertain. However, as with other Neoproterozoic acritarchs (Vidal 1990b), the possibility remains that *C. circularis* is the reproductive stage (e.g. cyst, aplanospore or zygote) of a thallophyte. While this possibility can neither be proved nor disproved, there is compelling evidence suggesting that metaphytic green and red algae were extant in Neoproterozoic times (Butterfield *et al.* 1988; Zhang 1989; Grant *et al.* 1991; Zhang and Yuan 1992).

The present record of the association of *Chuarina* and *Tawuia* is accompanied by diagnostic acritarchs including the large acanthomorph *T. vidalii*, a time-diagnostic species linking the present assemblage to other dated assemblages in Baltoscandia, the Scandinavian, Greenland and Svalbard Caledonides, China and western North America. The inferred age is Neoproterozoic (late Riphean) and bracketed around 840–700 Ma, which thus predates the Varanger glacial event in all areas of discovery.

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TEXT-FIG. 7. Geographical occurrence and stratigraphical range of organic-walled fossils recovered in the investigated Khastakh 930 sequence. Rectangular bars indicate established occurrences. Black circles indicate the occurrence of species probably conspecific with *T. vidalii* in the Kildin Group and the occurrence of *Trachyhystrichosphaera stricta* (probably a junior synonym of *T. vidalii*) in the Miroedikha Formation. Isotopic dates indicate bracketed ages in million years.

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